The Effects of Ionizing Radiation on Wear-out and Reliability of Thin Gate Oxides

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Abstract

Thin SiO_2 films having thicknesses of 3.2 nm and 7.3 nm were subjected to ^{60}Co gamma irradiation with a total dose up to 30 Mrad. Constant voltage TDDB experiments were performed with the silicon surface biased in accumulation. Weibull breakdown distributions were obtained after selected total doses and compared to those obtained prior to the irradiation. Changes in breakdown distributions as a function of total dose are compared to changes observed in radiation-induced leakage currents (RILC).

Introduction

Future planned robotic exploration missions to Europa will require electronics with ultra-high levels of radiation tolerance (»1 Mrad). Although radiation only produces a modest shift in the threshold voltage in the thin gate oxides used in advanced MOS technology, these thin oxides are still susceptible to radiation-induced effects. In recent years,[1-6] several groups have reported on a variety of new radiation-induced effects in thin gate oxides, including radiation-induced leakage current (RILC) in gamma and electron irradiated oxides, single-event gate rupture (SEGR), and radiation-induced soft breakdown (RSB) in oxides exposed to high LET heavy ion irradiation. Despite this work, the effects of radiation on the wear-out and long-term reliability of ultrathin oxides below 4nm have not yet been well characterized. In this work, we report on the effects of ^{60}Co gamma on RILC and the long-term reliability of industry-supplied 3.2 nm and 7.3 nm thick SiO_2 films.

Experimental Details

Test capacitors having oxide thicknesses of 3.2 nm and 7.3 nm and areas of 1 X 10^5 um^2 and 2.5 X 10^3 um^2 respectively were patterned on industrial-supplied wafers. The wafers were fully processed with both *n*-well and *p*-substrate versions of the test devices available.

Constant voltage time-dependent dielectric breakdown (TDDB) tests have been performed with the gate biased in accumulation. The 3.2 nm *n*-well and *p*-substrate samples were stressed using stress gate voltages of +/- 4.8 V and +/- 5.0 V. The 7.3 nm *p*-substrate sample was stressed with a gate voltage of – 10.5 volts.

The NIST gamma cell radiation source was used and provided a dose rate of approximately 6.5 KGray/hr. All irradiations were performed with the gate electrode unbiased because it has been reported by Ceschia [3] that the maximum RILC was observed at this condition. Failure distributions were obtained before and after gamma irradiation with a total dose of 1 Mrad(Si), 5 Mrad(Si), 15 Mrad(Si), 20 Mrad(Si), and 30 Mrad(Si).

I-V characteristics were measured immediately following each exposure to determine if any RILC relaxation effects occurred. All of the IV characteristics relaxed to a stable value after about 2 hours following each irradiation. Reliability tests were commenced following this relaxation time.

Radiation-Induced Leakage Current (RILC)

Figures 1a and 1 b show the change of low-voltage leakage current following the ^{60}Co gamma exposure

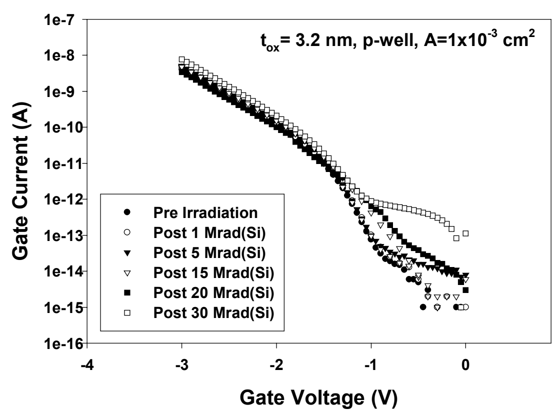

Fig. 1a.Leakage current characteristics following gamma irradiation for the 3.2 nm thick oxide on *p*-substrate.

for the 3.2 nm oxide. Figure 1a shows the change of leakage current for the *p*-substrate device and figure 1 b shows the change of leakage for the n-well device.

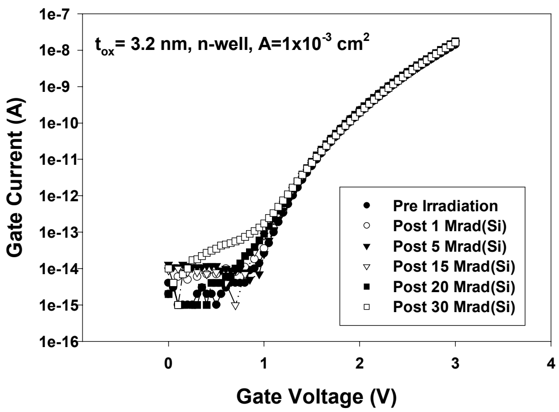

Fig. 1b.Leakage current characteristics following gamma irradiation for the 3.2 nm thick oxide on *n*-well.

Note that leakage current does not significantly increase until a total dose of 15 Mrad(Si) is achieved. The 7.3 nm thick samples exhibited a minimal increase in RILC after a total dose of 30 Mrad(Si), as shown in Fig 2.

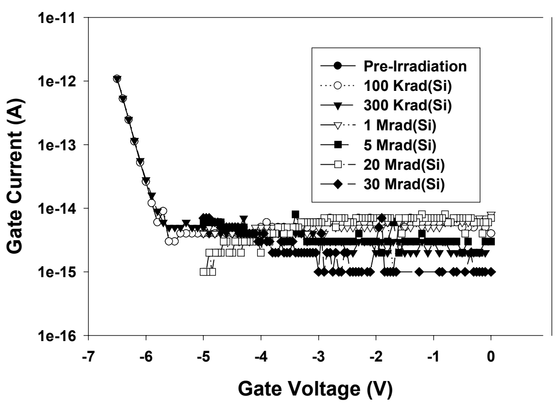

Fig. 2.Leakage current characteristics following gamma irradiation for the 7.3 nm thick oxide. The leakage current does not exhibit a significant increase up to a total dose of 30 Mrad(Si).

Time-Dependent Dielectric Breakdown

After each gamma exposure, a set of the devices were subjected to constant voltage TDDB measurements at a stress voltage of 5.0 V. Figure 3 shows the Weibull distributions obtained for the 3.2 nm *p*-well samples.

It appears that the gamma irradiation slightly increased the time-to-failure in this case. However, there is no clear trend in the data following the irradiation, as indicated by the increase in lifetime exhibited after the 1 Mrad total dose and the subsequent decrease exhibited after the 5 Mrad total dose. The lifetime then appears to increase again following the 20 Mrad total dose.

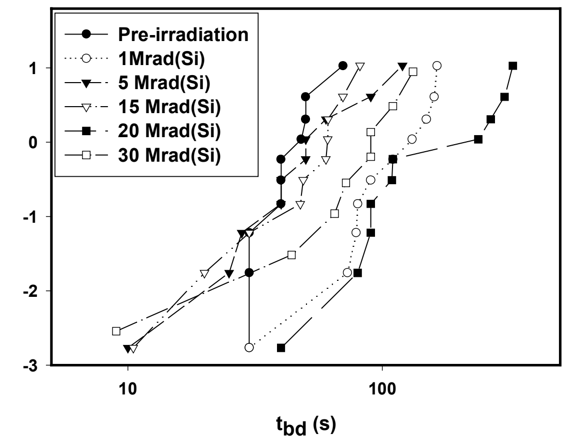

Fig. 3. TDDB Weibull distributions for the 3.2 nm *p*-well samples stressed at -5.0 V.

A similar behavior is observed for the 3.2 nm *n*-well samples, as shown in figure 4.

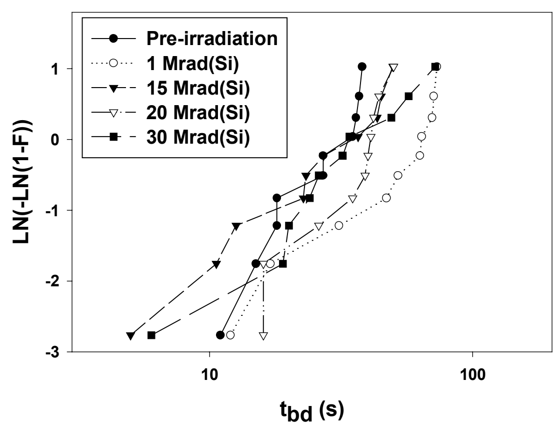

Fig. 4 TDDB Weibull distributions for the 3.2 nm *n*-well samples stressed at 5.0 V.

The breakdown statistics shown in figure 4 for the *n*-well devices exhibit much less of a change following each exposure. Additional testing with statistically larger samples would be required to determine if some of the trends observed in figure 3 and 4 are relevant.

Finally, figure 5 shows the TDDB failure distributions obtained for the 7.3 nm samples following gamma irradiation. Note that there is a small change in the failure time. However, there appears to be a broadening of the failure distribution, suggesting an increasing extrinsic failure mode. Such a broadening can not be observed in the failure distributions of the 3.2 nm oxide since the distributions are wider due to statistical reasons for ultra-thin films. Post irradiation modification of the cumulative distribution function was also observed by Paccagnella.[1]

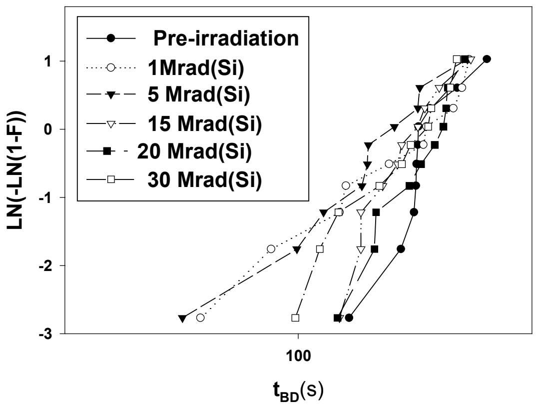

Fig. 5. TDDB failure distributions measured for the 7.3 nm oxide stressed at –10.5 V following gamma irradiation.

Conclusions

Thin SiO_2 films having thicknesses of 3.2 nm and 7.3 nm were subjected to ^{60}Co gamma irradiation with a total dose up to 30 Mrad. Radiation-induced leakage current was observed after 15 Mrad(Si) in the 3.2 nm oxides. The thicker films showed a minimal increase in leakage current following a total dose of 30Mrad (Si).

Although the gamma exposure increased the low-level leakage current in the thinner films, constant voltage TDDB experiments indicate that the irradiation had a minimal effect on the intrinsic lifetime in agreement with previous reports.[1,7] There appears to be a broadening of the failure distributions in the 7.3 nm film following exposure, however, additional experiments are required with statistically significant samples to validate the observation.

Acknowledgements

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